

# PATENT SPECIFICATION

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DRAWINGS ATTACHED.

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## COMPLETE SPECIFICATION.

### Tank for the Storage of Liquefied Gas and Method for its Construction.

We, GAZ DE FRANCE—SERVICE NATIONAL, a French Body Corporate of 23 rue Philibert Delorme, Paris 17e, France, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a tank, and to a method of constructing the tank, for the storage of liquefied gases, for example natural gases, at very low temperature and at a pressure close to atmospheric pressure.

Tanks for the storage of liquefied natural gas have already been made of prestressed concrete. These tanks are employed as a rule for underground storage of the liquefied gas. The prestressing of these known tanks is produced by means of steel cables tensioned along the vertical direction of the so-called skirt or cover, and in the form of coils of special steel externally surrounding the said skirt. Grouting or liquid mortar, applied by the pneumatic method, covers the coils or spirals of the prestressing cables outside the concrete skirt. Sealing in respect of the liquid stored and of its vapour is assured by means of a sheet of stainless steel covering the concrete outside the tank or immersed in the concrete. Heat insulation is provided by applying a known insulating material such as glass foam for example, on the outside of the concrete. To prevent humidity from impairing the quality of this outer heat insulation, an outer sheath is applied over the same to shelter it from atmospheric humidity or from that of the surrounding soils, depending on whether the tank is above or below ground.

In this type of known tank, the steel wires or steel bars employed to prestress the reinforced concrete tank must be of special

quality (elastic at low temperature) since they are exposed to the very low temperatures prevailing in the tank, given that there is no insulation between the concrete and the cold liquid stored, and in addition, the concrete is relatively permeable to liquid methane whose viscosity is approximately half that of water.

By contrast, in a tank according to the invention, a sealing "film" or liner prevents the volatile liquid stored from penetrating into the heat insulation and into the concrete and, in addition, the layer of heat insulation appropriately insulates the concrete so that the contents of the tank are kept at a much higher temperature than that experienced in the case of the known tank hereinbefore referred to. As a result iron-work employed in the tank may be made of steels of a quality much closer to standard grades than those of the prior art.

According to the invention there is provided the method of constructing a tank for the storage of liquefied gases at very low temperatures and at a pressure close to atmospheric pressure, which consists of building a sealed enclosure of reinforced concrete and applying to the concrete an initial stress such that after contraction caused by the lowest temperature to be anticipated there remains a positive tension exerting a compressive action on the concrete to avoid cracking thereof, applying to the interior of the enclosure a substantially unbroken lining of heat insulating material, and applying to said lining a gaseous, liquid, and vapour impervious, pliable liner.

The invention also contemplates a tank constructed according to the method.

In order that the invention may be clearly understood one embodiment thereof will now be described, by way of example, with

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reference to the accompanying drawings, in which:—

Figure 1 illustrates a storage tank according to the invention, seen in elevation, with partial sectioning;

Figures 2 and 3 respectively illustrate in section along a vertical plane, the joints of the tank skirt, being the upper one to the roof and the bottom one to the base;

Figure 4 in section shows the different layers of heat insulation applied on the inner walls of the tank and the strengthening reinforcement of the final layer;

Figure 5 in section shows an anchoring element intended to suspend the liner or sealing film on the inner wall;

Figure 6 in cross-section, diagrammatically and to a larger scale, shows a piece of sealing film according to the invention;

Figure 7 is another view of the film of Figure 6 which shows the overlapping of the gas-sealing metal sheets making up the so-called film;

Figure 8 shows how the passage is formed for a pipe or duct passing through the wall of the tank according to the invention.

Referring to Figures 1 to 3, a tank for the storage of liquefied gas at very low temperature, comprises a sealed enclosure, of great mechanical strength, preferably made wholly or in part of reinforced concrete, and having a base 10, a skirt 12 and a roof 14. The inner walls of the tank are lined by a layer 16 of heat insulation the interior of which is, in turn, lined by an unbroken "film" or liner 18 which prevents direct contact between the stored liquid 20, and the vapour above it, and the insulating layer 16.

The skirt 12 of the tank is made of prestressed concrete and is formed from prefabricated panels similar in shape to the staves of a large barrel. These panels are prestressed along their greatest dimension (the vertical dimension). Sealing between the panels forming the skirt is produced by ramming a resilient mortar into grooves or recesses provided around the entire periphery of the panels. Vertical tension rods advantageously traverse the panels lengthwise thereof to effect vertical prestressing thereof.

Following the assembly of the panels, the skirt is radially prestressed by steel wires or cables wound round the skirt in one or more layers with the desired tension; the turns of the wires are shown at 22 in Figures 1 to 3.

The tension imparted to the wires or cables 22 is such that after contraction caused by the low temperature, there remains a positive tension exerting a compressive action on the concrete to avoid cracking thereof. The turns of the wires or cables 22 are covered with

a sheath 24 of protective mortar applied, for example, by spraying, to a thickness of several centimetres.

The roof 14 is of the self-supporting type, that is to say it has the form of an ellipsoid of revolution or of a hyperboloid on top of a horizontal plane. In this case, the peripheral stresses are absorbed by a peripheral ring of reinforced concrete 26 (Figure 2).

According to a variant which is not illustrated, the roof may be made in the form of a cap, either shaped as an ellipsoid or revolution or a hyperboloid over a horizontal plane, made of metal plates, either of nickel steel alloy, or of aluminium alloy. In this case, the roof may be constructed separately and then placed on the skirt with the interposition of a sealing joint and appropriate anchoring devices between it and the top of the concrete skirt.

It is evident that it is appropriate to allow for the weight of the roof when calculating the initial stress to be imparted to the elements of the skirt 12.

Alternatively the roof may be flat and supported on pillars.

The tank, the capacity of which is of the order of several tens of thousands of cubic metres, preferably has a skirt height equal to its radius, the skirt being cylindrical.

If employed above ground, the tank comprises a foundation or base 10, ventilated in such manner as to prevent freezing to the ground. By contrast, if the tank is wholly or partly buried, the space left between the pit and the outer walls of the tank is filled with dry sand, with appropriate draining of the surrounding terrain. In the case of a buried tank, the thickness of the heat insulation 16 may be reduced if it is permitted to accept a predetermined degree of freezing of the surrounding earth, the surrounding mass of sand being a medium of isotropic permeability intended to prevent the formation of ice "lenses" which would generate dangerous stresses.

Rigid coupling between the skirt and base and between the skirt and roof is avoided and Figure 2 shows the coupling it is possible to establish by anchoring in the roof 14, perpendicularly with respect to the connecting joint of the roof with the skirt 12, a flat ring 28, and at the crest of the skirt 12, perpendicularly with respect to the joint, a flat ring 30, the rings 28 and 30 being connected by an annular member 32 forming a hermetic bellows. The member 32 is formed by a metal sheet folded into U-form, the metal being resilient at low temperature, such as stainless steel or copper alloy. A suitable lubricant is advantageously interposed between the facing flat parts of the members 28 and 30.

Figure 3 illustrates the coupling of the skirt to the base 10 by annular members 34

and 36, anchored perpendicularly with respect to the joint. The members 34 and 36 are connected to each other by means of a second annular member 38 formed by a metal sheet folded to U-form and forming a hermetic joint between the bottom of the skirt 12 and the periphery of the base 10. A suitable lubricant is inserted between the facing flat parts of the plates 34 and 36.

The heat insulation layer 16 applied internally to the base 10, to the skirt 12, and to the roof 14, is preferably made of expanded plastics material such as, for example, the sealed-cell type of foams of polyurethane or of epoxy resins. The heat insulation layer 16 for the skirt 12 and for the base 10 is produced either by moulding the insulation material in position or, preferably, by means of projection, for example by a spray gun, in the form of uniform layers of a thickness of 2 to 3 cms, the chemical reaction causing the expansion to occur immediately after application. To this end, the products employed are mixed with an appropriate reactant so that at the instant of application the bubbles resulting from the complex chemical reactions cannot be released during the time the product hardens; these bubbles are of the sealed type and make up 85% to 90% of the overall mass.

Figure 4 diagrammatically shows the insulating layer obtained by the consecutive application of seven coats of expanded plastics material on the concrete of the skirt 12. The outer surface 40 of each layer has a smooth skin which is impervious and represents a natural sealing barrier.

An improvement in the method of placing in position inner layers or coats exposed to the lowest temperatures, resides in reinforcing the final layers by insertion therebetween of very thin expanded metal, for example stainless steel or aluminium alloy, or a mesh-work of wires which have a polygonal section facilitating the anchoring of the resin to the metal. If desired there may be positioned between the layers or coats a fabric, having extremely slack meshes or loops, of glass fibre. A reinforcement as just described is shown diagrammatically at 42, Figure 4. The reinforcement has the result of preventing cracking of the expanded plastic during contraction thereof at the very low temperatures.

It will be noted that the materials selected are such that the adhesion between the layers, and that between the base layer and the concrete, is greater than the internal strength of the material. The insulating layer thus formed is anisotropic, but in one piece. The method of application by spray-gun may prove difficult to perform for the lining of the roof 14. Accordingly, given that the roof is in contact only with the vapour above the stored liquid 20, the roof may be insulated

by known devices such, for example, as pre-fabricated panels of expanded polyurethane, or of polyvinyl chloride, which are secured by bonding or in any other suitable manner.

Alternatively, as illustrated in Figures 2 and 3, a shoulder or the like is formed in the connecting angle or corner between the skirt and the roof (Figure 2) and in that between the skirt and the base (Figure 3) by means of specially made rigid blocks of insulating material. The blocks, when placed in position, surround the annular bellows members 32 and 38 which are thus given free play in a cavity stuffed with heat insulation, such as compressed glass wool, or soft wadding or packing of expanded plastic, which is pliable at the lowest temperatures experienced. The packing block of heat insulation surrounding the bellows member 32 is shown at 31 (Figure 2), and that surrounding the bellows member 38 is shown at 37 (Figure 3). In the junction 46 between the skirt and roof, and 48 between the skirt and base, there are grooves or the like which improve the contact between the packing blocks 31, 37 of polyurethane and the layers of polyurethane deposited on the skirt 12. In an alternative, not illustrated, it is possible to form the blocks by covering the base portion of the bellows members with one or more layers of plastics material applied by projection, for example by spraying, in such manner as to assure the continuity of the vertical and horizontal surfaces of the shoulders.

The "film" or liner 18 shown diagrammatically in Figures 1 to 3 is formed of a composite sheet. As is more clearly apparent in the diagrammatic Figures 6 and 7, this "film" or liner comprises a base fabric 50, Figure 6, on which are applied by a suitable method, e.g. by hot-rolling, an initial layer of plastics material 52, a very thin sheet of metal 54, then a second layer of plastics material 56. The fabric 50 is intended to withstand tractive stresses; it should remain pliable and withstand folding at the very low temperature (of the order of  $-160^{\circ}\text{C}$ ) it acquires when the tank is filled with liquefied gas. As the fabric 50, one may advantageously employ high-quality cotton fabric, or better still, a synthetic fabric, for example a fabric made of polypropylene or of glass fibres. The very thin sheet 54 is made of a metal easy to roll and which assures satisfactory imperviousness to gases, such as aluminium, copper or other metal retaining its qualities at the low temperatures. The sheets of plastics material 52 and 56 which are, for example, made of polyethylene or polypropylene should be inert to the action of the stored liquefied gas.

In Figure 7, there is shown in perspective and cross-section how the junction is made between two adjacent portions of "film" or

liner 18a and 18b with partial overlapping of the metal sheets 54a and 54b contained in the said portions. In the drawings, 52a and 56a indicate the sheets of plastics material applied against the metal sheet 54a, and 52b and 56b indicate those applied against the metal sheet 54b. The references 50a and 50b indicate the cotton or analogous fabric of the portions of "film" or liner 18a and 18b. In order to form the overlap of a few centimetres (shown along line 55) the metal sheets 54a and 54b have one of their faces stripped of plastic, being that covered by the plastics sheet 52a in the case of the metal sheet 54a, and that covered by the plastics sheet 56b in the case of the metal sheet 54b. The bared parts disposed face to face are glued together by means of an appropriate adhesive suitable for the lower temperatures in question.

The continuity of the composite "film" or liner 18a, 18b may then be established, for example, by welding if the plastics sheets are of a material weldable by heat.

According to the method of application shown in Figure 7, a covering plate 58 or the like is glued over the sheets 56a and 56b, and a covering plate 59 is glued over the fabrics 50a and 50b. The covering plate 58 is preferably of the same material as the sheets 56a and 56b, and the covering plate 59 is preferably of the same material as the fabrics 50a and 50b.

It will be understood that where appropriate, it is possible to assemble continuous areas of "film" or liner 18 by lap welding of plastics sheets without performing any special bonding of the metal sheets.

When the consecutive strips or webs of "film" or liner have been assembled by welding, the liner formed is suspended gradually from suspension devices anchored in the wall of the tank.

Figure 5 illustrates the suspension of the "film" or liner 18 by means of a web 60 of strong fabric glued or sewn to the supporting fabric 50. This suspension is performed by means of a ring, clip-hook, loop or the like 62 which passes over a screw eye or hook 64 screwed into a wooden block 66 anchored in the insulating mass 16. A small plate 65 of stainless steel or the like is disposed between the hook 64 and the "film" or liner 18. The cavity 67 which is formed between the "film" or liner 18, the block 66, and the insulating material 16, is preferably filled with a packing of bonded glass wool or the like. Numerous screw hooks 64 thus anchored are incorporated in the heat insulation 16. They are mounted at predetermined intervals in such manner that between two consecutive suspension points, the fabric forms a fold preventing its tensioning during contraction caused by low temperature. The "film" or liner 18 in fact simply forms a sealing skin; it need not withstand any mechanical tractive

force and need merely transmit the thrust of the liquid to the heat insulation which itself transmits the same to the strong wall of prestressed concrete.

Due to its composite nature, the "film" or liner has very interesting characteristics. The layers of plastics material which are impervious to the liquid, are but partially so in respect of the gases, but the thin metal sheet interposed between two layers of plastics sheet is impervious to the gas resting above the liquid. It is possible moreover to superimpose several layers of the "film" or liner.

Sealing between the sealing "film" or liner 18 and the metal or other elements which must traverse the concrete walls and the heat insulation, is assured, for example, by an assembly employing a flange and counter-flange between which are gripped the "film" or liner on the one hand, and a sealing joint on the other.

A pipe 70, made from a metal which is resilient at the low temperatures, may be passed through the skirt 12 of the tank, and is shown in Figure 8. The pipe 70 is housed in an aperture 72 formed in the concrete of the skirt. A cast plastics cement packing 74 is positioned between the pipe 70 and the walls of the aperture 72 in the skirt 12. The pipe 70 has fins 71 in the part traversing the heat insulation. The fins 71 have the effect of increasing the area of dispersion along the pipe 70. Studs 78 of metal resilient at low temperature are welded or screwed on a flange 76 welded to the extremity of the pipe 70.

The "film" or liner 18, which is pierced by a hole the diameter of which is substantially that of the inner diameter of the pipe 70, covers the inner face of the flange 76 and lies in the plane of the inner surface of the heat insulation 16. Inside the tank there is a pipe 80, similar to the pipe 70, and provided with a flange 82 which is mounted on the studs 78 with the interpolation of a sealing joint 84, for example formed by a copolymer reinforced by a glass mat or fabric.

The normal stages in the construction of the tank which has been described, are as follows:—

Foundations are laid, for example on the posts driven into the earth, illustrated in broken lines in Figure 3, having the flat tops supporting a horizontal slab carrying bearing blocks. A prestressed base 10 is disposed on the slab and on the base are mounted the first row of prefabricated panels forming the lower portion of the skirt, a sealing joint being interposed between the bottoms of the panels and the base and capable of permitting expansion. Sealing between the panels is assured by packing of the grooves or the like with an appropriate plastics mortar. The second and subsequent rows of panels are threaded over vertical reinforce-

ments passing through holes extending lengthwise through the panels. The vertical reinforcements make it possible to provide the tank with the appropriate prestressing, allowing for the weight of the roof which is to rest on the top of the skirt. External prestressing is then carried out by applying the prestressing wires or cables 22. Following the fitting of an upper sealing joint the rings 28, 30 are fitted and then the roof is fitted. The layer of prestressing wires or cables 22 is then covered with grouting, and the inlet or outlet pipes for the fluids are fitted in position with a packing of cast plastics cement.

The second stage consists of applying the consecutive layers of heat insulation 16, and then after placing in position, if appropriate, packing blocks 31, 37 around the expansion bellows, of fitting in position the heat insulation panels of the roof, and when all the heat insulation has been placed in position, of fitting the hooks 64 from which the sealing "film" or liner is to be suspended.

The final stage consists of preparing composite "film" or liner panels, suspending the panels from the hooks, and then performing welding operations in position within the tank for the assembly of the liner panels, and forming seals around the pipes or other conduits traversing the walls.

A tank constructed as described with reference to the drawings has its mechanical strength wholly provided by a shell or casing of prestressed concrete, whereas thermal insulation is assured by a foam of plastics material having excellent insulating characteristics, sealing being assured by the liner which bears against the heat insulation, which latter transmits the internal forces to the strong external casing or shell.

The risk of accidents when using the tank are reduced to a minimum because of the numerous barriers against leakage provided consecutively between the stored liquid and the outside of the tank, such barriers being the composite "film" or liner, then the consecutive layers of thermal insulation, which is impervious unless it is cracked, and this is guarded against by the reinforcement thereof in the regions thereof which are exposed to the lowest temperatures, and finally, the concrete enclosure which has a certain degree of hermeticity due to the connecting bellows between the skirt and roof on the one hand, and between the skirt and the base on the other hand, and which by itself withstands very low temperatures very satisfactorily.

#### WHAT WE CLAIM IS:—

1. The method of constructing a tank for the storage of liquefied gases at very low temperatures and at a pressure close to atmospheric pressure, which consists of

building a sealed enclosure of reinforced concrete and applying to the concrete an initial stress such that after contraction caused by the lowest temperature to be anticipated there remains a positive tension exerting a compressive action on the concrete to avoid cracking thereof, applying to the interior of the enclosure a substantially unbroken lining of heat insulating material, and applying to said lining a gaseous, liquid, and vapour impervious, pliable liner.

2. The method according to Claim 1, wherein the heat insulating material consists of expanded synthetic plastics material, for example foamed polyurethane or epoxy resins having sealed-type cells, and the material is applied as superimposed layers by moulding or by projection for example by a spray-gun.

3. The method according to Claim 1, wherein the heat insulation consists of prefabricated panels of heat insulating material.

4. The method according to Claim 3, wherein the panels are adhesively secured to the interior of the enclosure, or are attached to the interior of the enclosure by known forms of attachment devices.

5. The method according to Claim 2, or Claim 3, or Claim 4, including the step of reinforcing the heat insulating material by expanded metal, or a grid or mesh of metal, which is resilient or elastic at the low temperatures to be experienced, or by a fabric having large meshes or loops of glass fibre.

6. The method according to any one of Claims 1 to 5, wherein the liner is formed from panels each formed by bonding or hot-rolling a supporting fabric which remains pliable at the lowest temperatures anticipated, and two sheets of plastics material between which there is positioned a thin sheet of metal which is resilient at low temperatures.

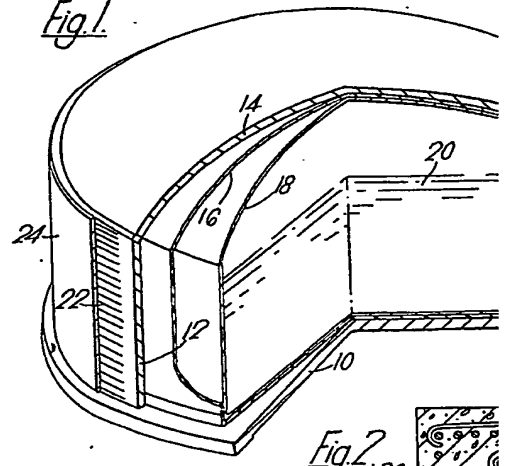
7. The method according to Claim 6, wherein the panels are united to form a unitary liner, the panels are suspended from devices anchored in the heat insulating material, and the adjoining panel portions are folded to prevent excessive tensioning of the unitary "film" or liner at the low temperatures.

8. The method according to Claim 7, wherein the panels are bonded by adhesive or by heat-welding and wherein the metal sheets are overlapped and adhesively adhered to each other.

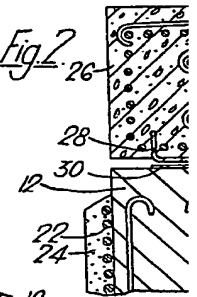
9. A tank for the storage of liquefied gases at very low temperatures and at a pressure close to atmospheric pressure, comprising a sealed enclosure of reinforced concrete to which there is applied an initial stress such that after contraction caused by the lowest temperature to be anticipated there remains a positive tension exerting a

- compressive action on the concrete to avoid cracking thereof, a substantially unbroken lining of heat insulating material applied to the interior of the enclosure, and a pliable  
5 liner made of gaseous, liquid, and vapour impervious material, applied to the lining of heat insulating material.
10. A tank according to Claim 9, wherein the enclosure comprises a roof and a base connected by a substantially vertical cylindrical skirt constructed from interconnected panels arranged in superimposed rows, the panels being provided with vertical reinforcing elements imparting thereto a compressive prestressing, and the skirt being encircled by prestressing wires or cables covered by grouting.
11. A tank according to Claim 9 or Claim 10, wherein the heat insulating material consists of expanded synthetic plastics material, for example foamed polyurethane or epoxy resins having sealed-type cells.
12. A tank according to Claim 11, wherein the heat insulating material is reinforced by expanded metal, or by a grid or mesh of metal, which is resilient or elastic at the low temperatures to be experienced, or by a fabric having large meshes or loops of glass fibre.
13. A tank according to any one of Claims 9 to 12, wherein hooks or the like  
are provided in the heat insulating material, said hooks being adapted to have the "film" or liner suspended therefrom.
14. A tank according to Claim 13, wherein the liner is formed from panels each formed by bonding or hot-rolling a supporting fabric which remains pliable at the lowest temperatures anticipated, and two sheets of plastics material between which there is positioned a thin sheet of metal which is resilient at low temperatures.
15. A tank according to Claim 14, wherein the supporting fabric is a cotton fabric or is a polypropylene fabric.
16. A tank according to Claim 14 or Claim 15, wherein the two sheets of plastic material are sheets of polyethylene or polypropylene.
17. A tank according to any one of Claims 14 to 16, wherein the thin metal sheet is a sheet of aluminium or of copper.
18. A tank for the storage of liquefied gases at very low temperature and at a pressure close to atmospheric pressure, substantially as herein described with reference to and as illustrated in the accompanying drawings.
- PAGE, WHITE & FARRER,  
Chartered Patent Agents,  
27, Chancery Lane,  
London, W.C.2,  
Agents for the Applicants.

*Fig. 1.*



*Fig. 2.*



*Fig. 3.*

